ALGORITHM FOR DETECTION OF UTERINE CONTRACTIONS FROM ELECTROHYSTEROGRAM

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Abstract-**At present, the most widespread method of monitoring of uterine contractions activity during pregnancy and labour is the external tocography. This mechanical method, however, has limited value resulting from its low accuracy and sensibility. Recent progress in new techniques of perinatal monitoring requires more precise method of monitoring uterine activity. The most promising seems to be the electrohysterography, which consist in recording of electrical uterine activity by means of electrodes attached to abdominal wall. We made an attempt to evaluate the possibility to replace the traditional mechanical method by the electrical one. We developed methods of extraction of slow wave from electrohysterogram. This slow wave corresponds to mechanical signal and can be regarded as a contractions wave. Then, using this wave, the contractions detection can be performed in a similar way as in conventional tocogram. The results obtained allow to conclude that there is close relation between electrical and mechanical signals of uterine activity. It manifests by similar number of contractions detected and large number of contractions being consistent.**
Keywords **- electrohysterography, uterine activity, signal processing**

I. INTRODUCTION

Mechanical contractions are released as a result of propagation of electrical excitation and appear in a form of intrauterine pressure increase. This increase of pressure exerted by uterus on abdominal wall is an indirect effect of uterine contraction. At present, the most widespread method for monitoring of uterine contractions activity during pregnancy and labour is the external tocography (TOCO). Common application of tocography is a result of its noninvasive and simple measurement technique. The contractions are recorded by tensometric transducer attached to patient's abdomen and held in a place with stretch belt. This method, however, has limited value resulting from its low accuracy and sensitivity, and the measurement of resting pressure is impossible. Contractions rate is indeed measured with accuracy comparable to direct measurement of intrauterine pressure, although the duration – with lower precision, while the amplitude value in merely approximate way represents the strength of contraction.

At present, tocography is an integral part of cardiotocography – the basic method of monitoring a fetal condition, using measurement of fetal heart rate. First and foremost, the tocogram is used to control the labour progress, although it is also a source of additional information for reliable management of a high-risk pregnancy. The waveform of mechanical uterine activity (TOCO) appears as a slow wave which amplitude increases according to uterine contractions. The tocogram vary in established range from 0 to 100 in relative units. Computer-aided analysis of signal comprises the detection of contractions and calculation of their basic descriptive parameters: starting time, duration, amplitude and area. Measurement of these parameters supports the medical staff with visual assessment of tocogram.

In the last decades, there is noted a growing interest in monitoring of electrical activity of uterus – electrohysterography (EHG). It consists in recording of action potentials of myometrium cells by means of electrodes positioned on mother's abdominal wall [1]. First attempts to obtain electrohysterogram from abdominal wall have been undertaken already in 1960s. However, insufficient level of measurement technology and lack of computer-aided digital signals processing, have made difficult the development of this technique and its use in clinical practice. Electrohysterogram investigations carried out in last years were focused mainly on the filtration of noise and artefacts originated from other organs as well as on the determination of time and frequency parameters of EHG signal [2, 3]. Electrohysterogram recorded in later gestation weeks and during a labour consists of evident action potential bursts produced by myometrium cells. There are two components which can be distinguished: slow and fast waves. Slow wave represents occurrence of bursts, whereas the fast wave is associated with frequency band of burst. Action potential bursts are synchronized with mechanical contractions. Presented paper is concentrated on the analysis of electric activity signal and evaluation of the possibility to replace the traditional mechanical method by the electrical one.

II. METHODOLOGY

Electrohysterogram analysis leading to detection of contractions consists of two stages. At first stage, a slow wave should be determined from the raw EHG signal. This component corresponds to TOCO signal and can be regarded as a contractions wave. Then, using this wave, the contractions detection can be performed in a similar way as in conventional tocogram. Two methods for determination of contractions wave have been developed: with the use of filtration or statistics.

Filtration method. EHG signal can be simply characterized as an action potentials fast wave having amplitude modulated by the slow wave corresponding to contractions. The concept of amplitude modulation and reverse operation – demodulation is presented in Fig. 1. Frequency of signal A is selected to correspond with a lower frequency of fast wave band, i.e. 0.1 Hz. Signal B simulates the typical contraction activity – 3 contractions per 10 min – corresponding with the

0-7803-7211-5/01$10.00©2001 IEEE

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
25 Oct 2001	N/A	-

Title and Subtitle Algorithm for Detection of Uterine Contractions From Electrohysterogram	**Contract Number**
	Grant Number
	Program Element Number
Author(s)	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Institute of Medical Technology and Equipment Zabrze, Poland	**Performing Organization Report Number**
Sponsoring/Monitoring Agency Name(s) and Address(es) US Army Research, Development & Standardization Group (UK) PSC 802 Box 15 FPO AE 09499-1500	**Sponsor/Monitor's Acronym(s)**
	Sponsor/Monitor's Report Number(s)

Distribution/Availability Statement
Approved for public release, distribution unlimited

Supplementary Notes
Papers from 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, Oct 25-28, 2001, held in Istanbul, Turkey. See also ADM001351 for entire conference on cd-rom., The original document contains color images.

Abstract

Subject Terms

Report Classification unclassified	**Classification of this page** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** UU

Number of Pages
4

frequency of 0.005 Hz. In frequency domain, the modulation process is associated with a shift of modulating signal spectrum to higher frequency bands. The frequencies of modulating signal are quite near the frequency of modulated signal. The contractions wave which plays the role of modulating signal can be determined in demodulation process. Demodulation consists of non-linear operation and low-pass filtration. The absolute value operator (signal D) has been applied as a non-linear operation. Next, the low-pass 0.02 Hz filtration was performed. This resulted in signal E which almost perfectly mirrors slow wave B. The frequency of low-pass filter can be set individually for each EHG record.

Other model of EHG signal was assumed in [4]. Basing on spectral analysis, the authors have stated that the frequency of action potentials can be related to the phase of the mechanical activity. Such a process can be seen as a frequency modulation. However, frequency modulation can be changed into amplitude modulation by means of signal differentiation. Then, the amplitude demodulation is carried out in order to determine a modulating signal – in this case – the contractions wave of EHG signal.

Statistical method. EHG signal envelope represents a change of action potentials amplitude around a certain resting potential. The standard deviation is a measure of how far the signal fluctuates from the mean. The mean value of EHG signal is zero because corresponding constant component is removed during recording with the use of band-pass filter. In such a case, the standard deviation is equal to root mean square of a signal:

$$\mathrm{RMS} = \sqrt{\frac{1}{n}\sum_{i=0}^{n} x_i^{\,2}} \tag{1}$$

Consecutive values of RMS are calculated in 60 sec window shifted with 3 sec step. Hanning window is used to compensate spectrum leakage effect according to following formula:

$$y_i = 0.5 \cdot x_i \cdot (1 - \cos\frac{2\pi i}{n}) \tag{2}$$

where: y_i – output signal sample, x_i – input signal sample, i – sample number and n – number of samples in the window.

In case of the tocogram, detection of contractions relies on finding those segments, which have value exceeding threshold level for the duration of 30 sec. As a threshold value we assumed a level of 10 units above so called basal tone. Apart from duration criteria, contraction amplitude should exceed 20 units. The basal tone is associated with the basal external

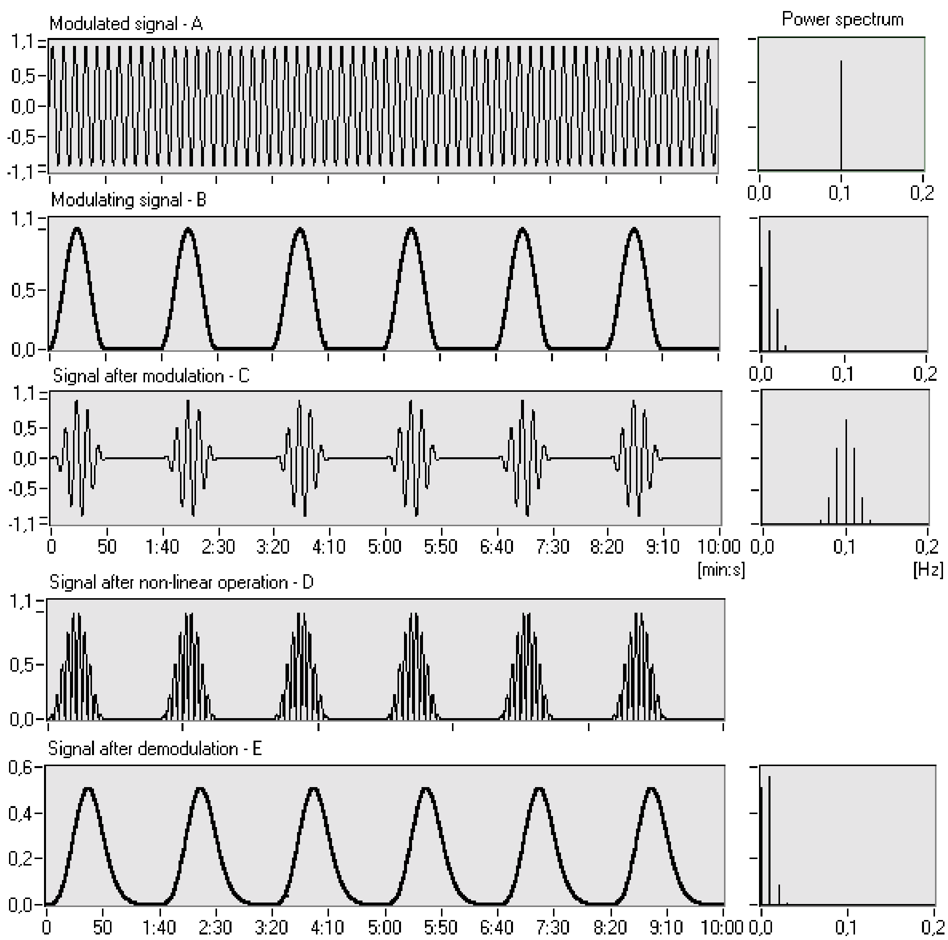

Fig. 1 Model of EHG signal based on amplitude signal modulation

pressure, which is measured by tensometric transducer when contractions do not occur. In case of electrohysterogram, the analysis is more complicated. Amplitude of signals recorded from abdomen wall undergoes a strong influence of: the type and location of electrodes, distance between them as well as differences in skin impedance. In this situation, there has been developed a method being insensitive to amplitude variability. Consecutive values of basal tone are determined in 4 min window and shifted with 1 min steps. In every step, samples are ordered from the lowest to the highest value, and the mean value from 10% of samples from the lowest value side is calculated. The threshold value for contractions detection is obtained by adding to basal tone the value equal to 25% of signal range (difference between highest and lowest value) in the analysed window. In this way, threshold for contractions detection varies along with the amplitude of analysed signal, whereas in tocography it is established arbitrarily. The contraction is recognized when its duration is greater than 30 sec and its amplitude is higher then double value of the threshold.

III. Results

We have acquired 112 records of uterine contraction activity using computerized system for simultaneous recording of electrical and mechanical uterine activity. This system has been described elsewhere in [5]. Recordings have been done in the last week of pregnancy to gain a good quality of signals and evident uterus contraction activity. Mean duration of these recordings was 40 ± 5 min.

Fig. 2 shows three contractions waves which have been extracted from a raw EHG signal using the methods described. EHG-F is the contractions wave determined by filtration method, while EHG-S – by statistical one. During development of the filtration method, the influence of frequency modulation on EHG signal was investigated. Prior to final amplitude demodulation, the digital derivative was taken thus obtaining EHG-F* signal. Comparison of EHG-F and EHG-F* curves shows that influence of frequency

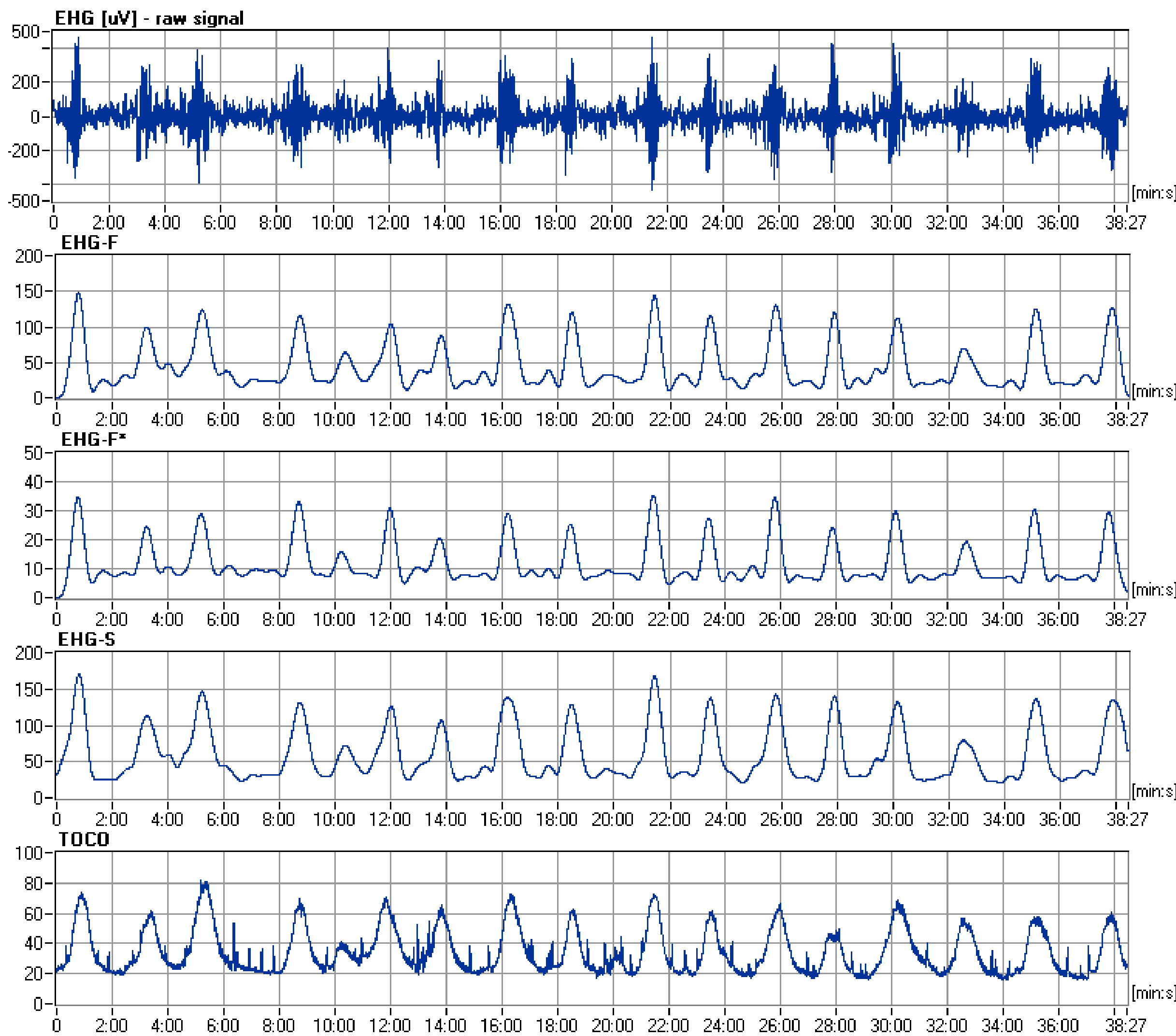

Fig. 2 Contraction waves determined from EHG signal

modulation is small and the amplitude-modulated signal is a good model of EHG signal.

The contraction curves determined with the use of EHG signal are very well correlated with the TOCO trace. The statistical method was chosen for further analysis. As it was proved by comparison, the statistical method has a higher sensitivity to short variations of action potential amplitudes. The filtration method provides stronger averaging and attenuation of amplitudes of action potential impulses. In addition, durations of contractions in EHG-S signal are slightly longer than in EHG-F signal, thus more approximating the contractions duration in the tocogram.

Detection of contractions was carried out using previously described criteria. There have been detected 1404 contractions in TOCO signals and 1540 contractions in electrohysterogram. The 1342 contractions have been determined using both methods and 87% of EHG contractions and 96% of TOCO contractions were regarded as consistent. The criteria of contractions consistence have been defined as follows: contraction beginning detected on a basis of slow wave of EHG signal should be prior to maximum of mechanical contractions; whereas maximum of EHG contraction should be between the start and end of mechanical one. These criteria allow the contractions comparison and they have been extracted from the analysis of phenomena being a background for electrical and mechanical myometrium activity and from relation between both signals.

IV. Conclusion

The results obtained allow to conclude that there is close relation between electrical and mechanical signals of uterine activity. It manifests by similar number of contractions detected and large number of consistent contractions. This concerns the last week of pregnancy, from which the recordings are obtained. In earlier gestational periods, the lower consistence of both the signals are to be expected. Higher number of EHG-based contractions than those from analysis of TOCO signals may indicate the better sensitivity of electrical method.

The synchronization of mechanical and electrical activity, which intensifies as the labour term comes, has become confirmed by many researchers. In most cases, they only stated a close relation between electrical and mechanical activity, and they didn't confirm this relation quantitatively. Large consistence in number and location of contractions gives the chance for application of electrohysterography in a clinical practice. However, the next stage of verification of electrical method, as the alternative to mechanical one, should be the comparison of detailed descriptive parameters of contractions being consistent.

Acknowledgment

This study was supported by the State Committee for Scientific Research, Warsaw, Poland (KBN Grant No. 8 T11E 03619).

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